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U.S. FISH & WILDLIFE SERVICE
REGION 6

CONTAMINANTS PROGRAM

Environmental Contaminants in the Aquatic Bird Food Chain of an Oil Refinery Wastewater Pond

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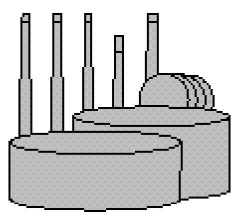

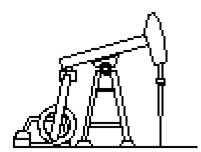

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ABSTRACT

Bird mortalities have been documented in oilfield waste pits in Wyoming and various other oil-producing states in the western United States. In the semi-arid West, migratory birds mistake wastewater ponds or pits for wetlands. Most refineries use large ponds to contain their wastewater. One refinery in Casper, Wyoming actively discharged refinery wastewater into a closed basin, Soda Lake. This created a wetland that attracts numerous aquatic birds, in particular, nesting colonies of gulls (*Larus* spp.), terns (*Sterna* spp.), double-crested cormorants (*Phalacrocorax auritus*), eared grebes (*Podiceps nigricollis*), dabbler ducks (*Anas* spp.) and American avocets (*Recurvirostra americana*). Soda Lake is a popular site with local birdwatchers. Wastewater was discharged into a small pond (Pond 1) adjacent to Soda Lake (Pond 2). Water from Pond 1 flowed through a spillway into Pond 2. The refinery ceased discharging wastewater in 1990. The objectives of this study were to determine if trace element and hydrocarbon concentrations in sediment and biota from Soda Lake are present in concentrations adverse to migratory aquatic birds. Selenium was elevated in aquatic invertebrates, bird livers and bird eggs but not in sediment or pondweed (*Potomageton vaginatus)*. Selenium concentrations were above threshold levels known to cause impaired reproduction and embryonic deformities in aquatic birds (Lemly 1993). Sediments collected near the inlet of Pond 1 contained elevated concentrations of chromium, copper, mercury and zinc. Sediments collected near the water inlet at Pond 1 had almost equal proportions of odd- and even-numbered aliphatics suggesting recent or chronic exposure to petroleum compounds. Carbon Preference Index (CPI) values for sediments from Pond 1 ranged from 0.58 to 1.1. CPI values less than 3 indicate oiled sediments (Farrington and Tripp 1977). Sediment samples from the inlet at Pond 1 also had high concentrations of oil and grease. Additionally, a visible sheen was observed on the water's surface after the sediments were agitated during collection. Odd-numbered aliphatics and pristane were greater than even-numbered aliphatics and phytane in pondweed and aquatic invertebrates. This indicates hydrocarbons of a biogenic origin. Hydrocarbons in gadwall livers collected from Pond 1 were probably petrogenic as indicated by approximately equal proportions of odd- and even-numbered aliphatics, high ratios of pristane and phytane to n-C17 and n-C18, respectively, and CPI values less than 3. Additionally, metabolized PAH's were detected in gadwall bile also suggesting exposure to petroleum hydrocarbons. Pond 1 had higher PAH concentrations in sediment and biota than did Pond 2.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

INTRODUCTION

Bird mortalities have been documented in oilfield waste pits in the western United States. In the semi-arid West, migratory birds mistake wastewater ponds or pits for uncontaminated wetlands. Most refineries use large ponds to contain their wastewater. One refinery in Casper, Wyoming actively discharged refinery wastewater into a closed basin, Soda Lake. This created a wetland that attracts numerous aquatic birds, in particular, nesting colonies of gulls (*Larus* spp.), terns (*Sterna* spp.), double-crested cormorants (*Phalacrocorax auritus*), eared grebes (*Podiceps nigricollis*), dabbler ducks (*Anas* spp.) and American avocets (*Recurvirostra americana*). Soda Lake is a popular site with local birdwatchers. The refinery ceased discharging wastewater in 1990. Closed basins similar to Soda Lake can contain elevated trace elements or other contaminants. Rasmus Lee and Goose lakes in the Kendrick irrigation project immediately west of Casper are closed basins with selenium bioaccumulation in the aquatic bird food chain (See et al. 1992). Soda Lake was used as a reference site for the Kendrick selenium study. Data obtained for the Kendrick study showed that mean selenium concentrations in aquatic vegetation and livers from juvenile grebes collected from Soda Lake were not elevated (See et al. 1992). Selenium data on aquatic invertebrates and aquatic bird eggs were not obtained during the Kendrick selenium study. Additionally, data on organic contaminants in the food chain were not available. The objectives of this study were to determine if trace element and hydrocarbon concentrations in sediment and biota from Soda Lake are present in concentrations adverse to migratory aquatic birds. This data will also provide baseline information for determining trends in selenium concentrations in biota inhabiting this closed basin.

STUDY AREA

Soda Lake is a man-made lake resulting from the discharge of wastewater from the AMOCO refinery at Casper, Wyoming (Figure 1). AMOCO discharged refinery wastewater into the Soda Lake basin from 1957 until 1990. Since then, AMOCO has pumped water from the North Platte River into Soda Lake to maintain aquatic bird habitat. Hydrologically, Soda Lake is a closed basin system comprised of two ponds, a small 70-acre pond (Pond 1) and the 650-acre lake (Pond 2). The smaller pond serves as the inlet and primary settling basin and is separated from the main lake by an earthen dike. Soda Lake provides habitat for 150 bird species (Metzger 1993). Two colonial waterbird rookeries occur at Soda Lake. These rookeries provide nesting habitat for double-crested cormorants , black-crowned night herons (*Nycticorax nycticorax*), California gulls (*Larus californicus*), and caspian terns (*Sterna caspia*). Puddle ducks , American avocets and eared grebes also nest at Soda Lake.

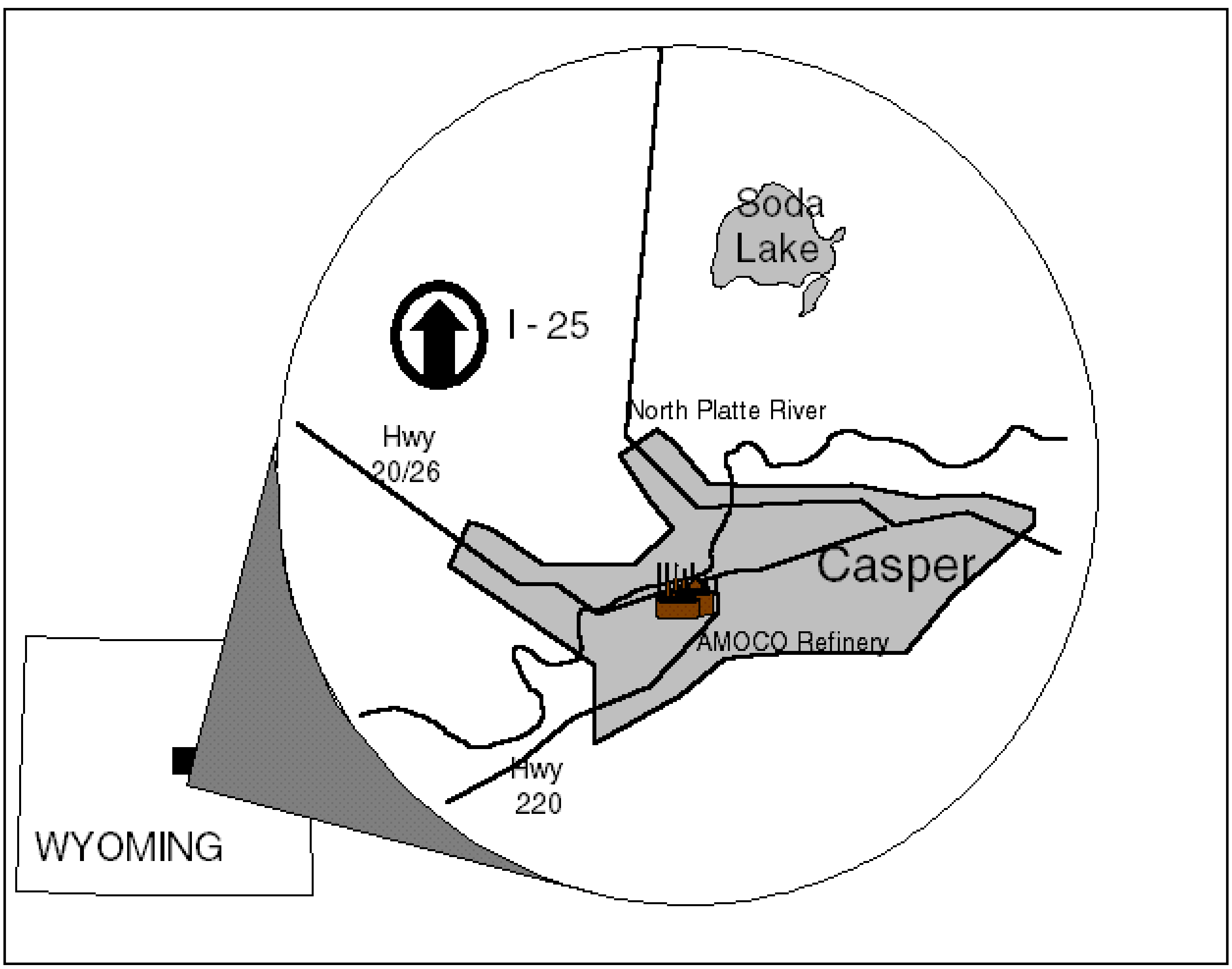

Figure 1. Location of Soda Lake, Natrona County, Wyoming.

METHODS

Sediment, aquatic vegetation, aquatic invertebrate, bird liver and bird egg samples were collected for chemical analyses at Soda Lake, Casper, Wyoming in 1992 and 1993 (Figure 2).

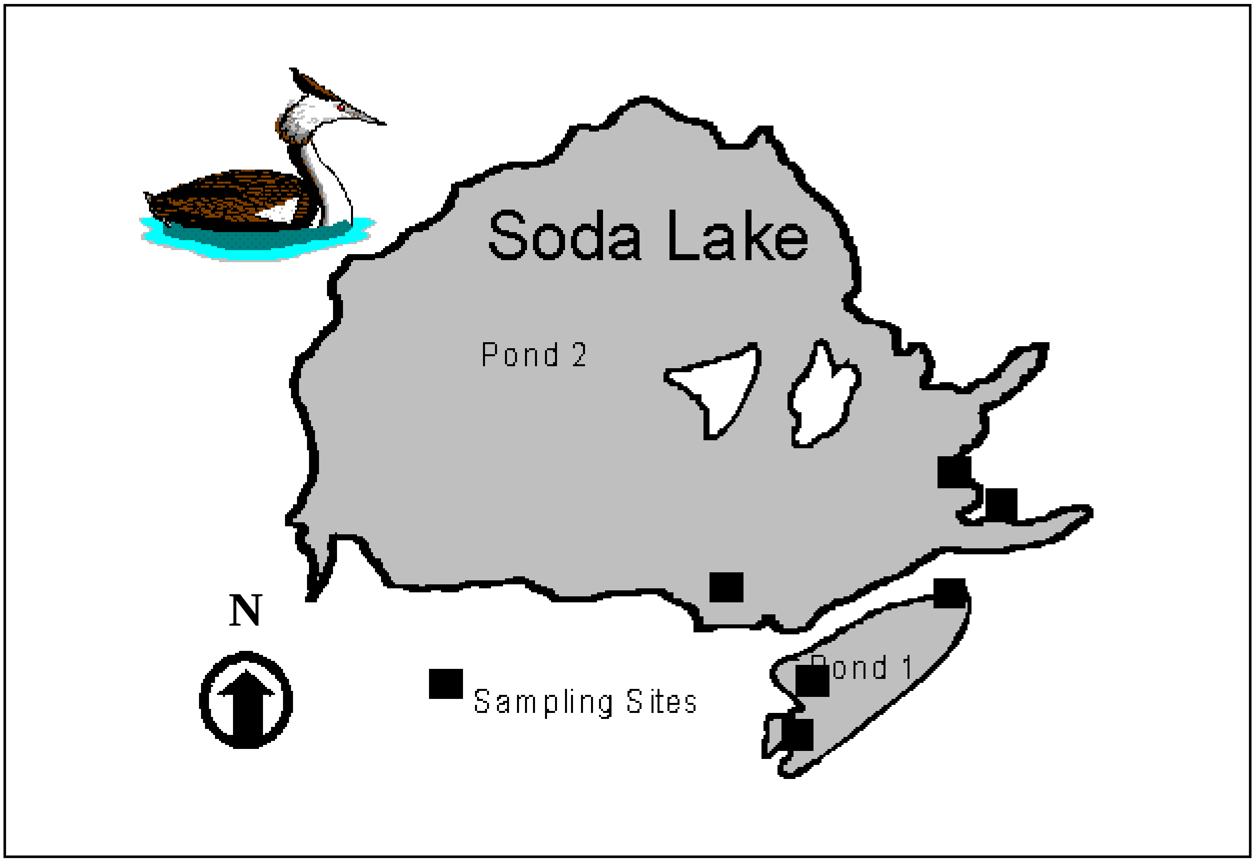

Figure 2. Sampling locations at Soda Lake, Natrona County, Wyoming.

Aquatic birds were also collected from a reference site at the Hutton Lake National Wildlife Refuge in Albany County, Wyoming. Sediment and biota samples collected for trace element analyses were placed in whirl-pak bags or chemically-clean glass jars with teflon-lined lids and frozen as soon as possible. Samples collected for hydrocarbon analyses were placed in chemically-clean amber glass jars or vials. Aquatic bird eggs were collected and dissected and the contents were submitted for trace element and hydrocarbon analyses. Embryos were aged and examined for deformities. Pre-fledged aquatic birds were collected during late July using a shotgun and steel shot. Liver and bile samples from each species were submitted for trace element and hydrocarbon analyses, respectively. Livers were dissected using chemically-clean dissecting tools. Bile was collected from the gall bladder using Vacutainers®.

Sediment and biota samples were submitted to the U.S. Fish and Wildlife Service's Patuxent Analytical Control Facility (PACF) or designated contract laboratories for trace element and hydrocarbon analyses. Trace element analysis included scans for: arsenic, mercury, and selenium using atomic absorption spectroscopy. Inductively Coupled Plasma Emission

Spectroscopy was used to scan for a variety of elements including boron, barium, copper, lead, vanadium and zinc. Radium was also analyzed in water and sediment samples by co-precipitation with barium sulfate and counted by alpha spectrometry. An extended scan for aromatic hydrocarbons was conducted on sediment and bird liver samples. Polycyclic aromatic hydrocarbons (PAH's) were analyzed in bird bile using high performance liquid chromatography. Quality assurance and quality control was provided by PACF. Trace element concentrations are expressed in µg/g (ppm) dry weight and in µg/g (ppm) wet weight for organics unless otherwise specified.

RESULTS and DISCUSSION

Petroleum Hydrocarbons

Aliphatics

Differentiating petrogenic from biogenic compounds in the interpretation of hydrocarbon residues in sediments and biota is important. Petrogenic compounds have approximately equal proportions of odd- and even-numbered aliphatics (Hall and Coon 1988). Also, high ratios of pristane and phytane to nC17 and nC18, respectively, indicate recent or chronic exposure to petroleum compounds (Anderson et al. 1978, Farrington et al. 1973, Hall and Coon 1988). The Carbon Preference Index (CPI) is also used to differentiate between oiled and non-oiled matrices (Farrington and Tripp 1977). Sediments collected near the water inlet at Pond 1 had almost equal proportions of odd- and even-numbered aliphatics (Table 1) suggesting recent or chronic deposition of petroleum compounds. CPI values for sediments from Pond 1 ranged from 0.58 to 1.1. CPI values less than 3 indicate oiled sediments (Farrington and Tripp 1977). Sediment samples from the inlet at Pond 1 also had high concentrations of oil and grease. Additionally, a visible sheen was observed on the water's surface after the sediments were agitated during collection. Odd-numbered aliphatics and pristane were greater than even-numbered aliphatics and phytane in pondweed and aquatic invertebrates (Table 1 and 2). This indicates hydrocarbons of a biogenic origin. Hydrocarbons in gadwall livers collected from Pond 1 were probably petrogenic as indicated by approximately equal proportions of odd- and even-numbered aliphatics, high ratios of pristane and phytane to n-C17 and n-C18, respectively, and CPI values less than 3 (Tables 1 and 2).

Aromatics

At the two Soda Lake ponds, PAH concentrations tended to be highest in sediment and vegetation and lowest in invertebrates (Tables 3, 4 and 5). At Pond 1, total PAH's ranged from 2.56 to 73.10 µg/g in sediments. These levels were usually higher than the maximum concentrations found in vegetation (26.77 µg/g) and invertebrates (3.15 µg/g)(Tables 3, 4, and 5).

Table 1. Total concentrations (in µg/g wet weight) of even- and odd-numbered aliphatics in sediments and biota from Soda Lake, Natrona County, Wyoming.

Matrix	Pond #	Total Even Numbered Aliphatics	Total Odd Numbered Aliphatics	Ratio Odd- / Even-Numbered Aliphatics	Carbon Preference Index (CPI)
Sediment	1	19.29	22.17	1.15	1.11
Sediment	1	19.9	22.14	1.11	0.58
Sediment	1	3.33	3.12	0.94	1.05
Pondweed	1	1.51	20.98	9.62	9.62
Pondweed	1	2.33	20.35	6.09	6.09
Odonate Larvae	1	3.37	9.19	2.72	3.25
Odonate Larvae	1	0.68	3.22	4.70	--
Odonate Larvae	1	1.12	9.09	8.08	--
Waterboatmen	2	3.64	13.41	3.68	2.69
Waterboatmen	2	6.95	44.70	6.43	3.73
Amphipod	2	2.21	12.15	5.49	--
Blue-winged Teal Liver	2	0.18	0.29	1.61	--
Gadwall Liver	1	1.20	1.63	1.36	0.84
Gadwall Liver	1	2.06	1.40	0.68	2.24

-- Not Calculable

Table 2. Concentrations of n-C17, pristane, n-C18 and phytane (in µg/g wet weight) in sediments and biota from Soda Lake, Natrona County, Wyoming.

Matrix (Pond #)	n-C17	Pristane	Pristane/ n-C17 Ratio	n-C18	Phytane	Phytane/ n-C18 Ratio	Pristane Phytane Ratio
Sediment (1)	3.40	20.26	5.96	1.84	15.15	8.23	1.33
Sediment (1)	3.69	20.31	5.50	1.94	14.51	7.48	1.39
Sediment (1)	0.30	0.91	3.03	0.09	0.85	9.44	1.07
Pondweed (1)	1.33	0.36	0.27	0.06	0.33	5.50	1.09
Pondweed (1)	1.45	1.15	0.79	0.14	0.92	6.57	1.25
Odonate Larvae (1)	0.48	1.51	3.15	0.27	1.32	4.89	1.14
Odonate Larvae (1)	0.21	0.65	3.10	BDL[1]	0.54	0.54	1.20
Odonate Larvae (1)	1.11	1.06	0.96	BDL	0.70	--	1.51
Waterboatmen (2)	0.16	BDL	0.00	BDL	BDL	--	--
Waterboatmen (2)	0.10	BDL	0.00	BDL	BDL	--	--
Amphipod (2)	0.32	0.09	0.28	BDL	0.17	--	0.52
Blue-winged Teal Liver (2)	BDL	BDL	--	BDL	BDL	--	--
Gadwall Liver (1)	0.04	0.27	6.75	BDL	0.19	--	1.42
Gadwall Liver (1)	BDL	0.83	--	BDL	0.91	--	0.91

-- Not Calculable
[1]BDL = Below Detection Limit

Chrysene, phenanthrene, fluorene, 2-methylnaphthalene, and benzo(a)anthracene were present in sediments from Pond 1 at concentrations that Long and Morgan (1990) associated with adverse effects in fish and aquatic invertebrates. Total metabolized PAH's in bile from two juvenile gadwall were 583.4 and 612.6 µg/g (Table 6). The concentrations of metabolized PAH's in bile from two juvenile gadwall collected from Pond 1 are considered quite high for waterfowl (Sue McDonald, Geochemical & Environmental Research Group, Texas A & M, College Station, Texas, pers. communication, September 23, 1993). PAH metabolites in the bile samples consisted of benzo(a)pyrene, naphthalene, and phenanthrene compounds. Bile from gadwall (two samples) and American avocet (one sample) collected at the Hutton Lake National Wildlife Refuge were all below detection limits (<1.282, <0.089, and <4.348 µg/g, respectively). Aromatic hydrocarbons were below detection in bird livers and eggs collected at Soda Lake.

Table 3. Total Polycyclic Aromatic Hydrocarbons (PAH's), oil and grease and carcinogenic PAH's (in ìg/g wet weight) detected in sediment from Soda Lake, Casper, Wyoming.

	Pond 1						Pond 2	
Sample #	1	2	3	4	5	6	1	2
# Compounds Detected	25	36	37	37	37	37	26	37
Total PAH's	2.56	52.49	6.62	43.13	52.92	73.10	6.20	3.34
Oil & Grease	826	NA[1]	NA	7,818	8,324	NA	NA	NA
benzo(a)pyrene	0.01	0.13	0.01	0.15	0.13	0.55	BDL[2]	0.004
benzo(b) fluoranthene	BDL	0.07	0.008	0.08	0.07	0.32	BDL	0.004
chrysene	0.08	0.90	0.05	1.04	0.9	3.13	0.01	0.01
indenopyrene	BDL	0.02	0.005	0.01	0.02	0.11	BDL	0.00

[1] NA = Not Analyzed
[2]BDL = Below Detection Limit

Table 4. Total Polycyclic Aromatic Hydrocarbons (PAH's) and carcinogenic PAH's detected in pondweed (*Potamogeton vaginatus*) (in ìg/g wet weight) from Soda Lake, Casper, Wyoming.

	Pond 1			Pond 2
Sample #	1	2	3	1
# Compounds Detected	15	19	37	23
Total PAH's	1.41	2.04	26.77	4.43
benzo(a)pyrene	BDL[1]	BDL	0.025	BDL
benzo(b) fluoranthene	BDL	BDL	0.03	BDL
chrysene	0.07	0.10	0.45	0.05
indenopyrene	BDL	BDL	0.01	BDL

[1] BDL = Below Detection Limit

Table 5. Total Polycyclic Aromatic Hydrocarbons (PAH's) and carcinogenic PAH's (in ìg/g wet weight) detected in aquatic invertebrates from Soda Lake, Casper, Wyoming.

	Pond 1				Pond 2			
Sample #	1	2	3	4	1	2	3	4
Common Name[1]	DF	DF	DF	DF	WB	WB	WB	A
# Compounds Detected	19	2	0	0	0	1	0	0
Total PAH's	3.15	0.21				0.07		
benzo(a) pyrene	BDL[2]	BDL				BDL		
benzo(b) fluoranthene	BDL	BDL				BDL		
chrysene	0.07	BDL				BDL		
indenopyrene	BDL	BDL				BDL		

[1] DF = Damselfly (Odonate); WB = Waterboatmen (Corixidae); A = Amphipod
[2] BDL = Below Detection Limit

Table 6. Metabolized Polycyclic Aromatic Hydrocarbons (PAH's) (in ìg/g wet weight) in bile from gadwall collected from Soda Lake, Casper, Wyoming.

	Benzo(a)pyrene	Naphthalene	Phenanthrene
Gadwall 1	2.6	310	300
Gadwall 2	3.4	300	280

All but one sediment sample from Pond 1 had total concentrations of aromatic hydrocarbons one to 12 times higher than in Pond 2 (Table 3). The maximum PAH level detected in vegetation in Pond 1 was almost six times higher than in Pond 2. Aromatic hydrocarbons have historically been detected in Pond 1 where AMOCO discharged its refinery wastewater for over 30 years. In 1986, levels in Pond 1 sludge were 837 µg/g at the inlet and 500 µg/g near the outlet of the pond (John Wagner, Wyoming Department of Environmental Quality, Cheyenne, Wyoming, pers. communication, October 28, 1993). PAH concentrations in sludge were 10 to 100 times higher in 1986 compared to 1992, two years after wastewater stopped entering Pond 1. Specific PAH's measured in the 1986 sludge (chrysene, fluorene, 2-methyl naphthalene, naphthalene, phenanthrene, and pyrene) were still present, albeit at lower concentrations, in the 1992 sediments (Appendix A1 and A2).

Up to 37 PAH's were detected in samples from each pond in Soda Lake. Sediment and vegetation samples from Pond 1 contained higher concentrations of almost every PAH compared to Pond 2 samples. Maximum PAH levels were higher in Pond 1 samples compared to Pond 2 (Table 3, 4, and 5). Non-carcinogenic PAH's found at Soda Lake included: anthracene, benzo(k)fluoranthene, benzo(g,h,i)perylene, benzo(e)pyrene, fluorene, fluoranthene, naphthalene, perylene, phenanthrene, and pyrene. These non-carcinogenic PAH's can potentially cause acute toxicity in some organisms (Eisler 1987). Benzo(k)fluoranthene (2.0 mg/kg/egg) caused 100% mortality in embryos from common eider (*Somateria mollissima*) domestic chicken (*Gallus domesticus*), turkey (*Meleagris gallopavo*), and mallard duck (*Anas platyrhynchos*) (Brunstrom et al. 1990).

Some carcinogenic PAH's detected in the Soda Lake samples included benzo(a)pyrene, benzo(b)fluoranthene, chrysene, and indeno(1,2,3-cd)pyrene. Of these compounds, benzo(a)pyrene is considered strongly carcinogenic, benzo(b)fluoranthene is carcinogenic, and chrysene and indeno(1,2,3-cd)pyrene are weakly carcinogenic, cocarcinogenic, or tumorogenic (Lee and Grant 1981, as cited in Eisler 1987). Benzo(a)pyrene and chrysene has been shown to induce embryotoxicity in mallards (*Anas platyrhynchos*). Based on topical applications to eggs, 0.036 x 10^{-3} µg benzo(a)pyrene/g and 0.273 x 10^{-3} µg chrysene/g caused deformities, growth reductions, and mortality (Hoffman and Gay 1981, as cited in Eisler 1987). In doses of 2.0 mg/kg/egg, benzo(a)pyrene and indeno(1,2,3-cd)pyrene severely decreased survival while chrysene caused a significant increase in lesions in embryos from common eider and domestic chicken, turkey, and duck (Brunstrom et al., 1990). PAH criteria have not been established for aquatic organisms or waterfowl (U.S. EPA 1980; WDEQ 1990; Margaret Heber, EPA, Washington, D.C., pers. communication, September 21, 1993).

Levels of carcinogenic PAH's were higher in Pond 1 than Pond 2 for sediment, vegetation, and waterfowl samples (Tables 3, 4 and 6). All carcinogenic PAH's were below detection in aquatic invertebrate samples from Pond 2 and only chrysene was detected in invertebrates from Pond 1 (Table 5). The largest benzo(a)pyrene levels were found in Pond 1 in two gadwall bile samples (2.60 and 3.40 µg/g). Chrysene levels were highest in sediment samples from Pond 1 (0.05 to 3.128 µg/g). All other concentrations of these four selected carcinogenic PAH's were less than 0.60 µg/g. At the reference site at Hutton Lake Refuge, metabolized carcinogenic PAH's in bird bile were all below detection limits (gadwall = <0.089 and <1.282 µg/g; American avocet = <4.348 µg/g).

<u>Trace Elements</u>

Selenium is the primary trace element of concern as elevated concentrations have been documented in the nearby Kendrick irrigation project (See et al. 1992). Selenium was elevated inbiota but not in sediment (Table 7). Selenium was slightly elevated in one pondweed sample from Pond 1 (>3 ìg/g dietary threshold, Lemly 1993). Aquatic invertebrates had selenium concentrations exceeding the 3 ìg/g dietary threshold. Liver samples from four of five blue-winged teals had selenium concentrations greater than the 10 ìg/g toxicity threshold reported by Lemly (1993). Selenium concentrations in eared grebe eggs exceeded the 3 ìg/g background level and were above the 8 ìg/g level associated with reproductive impairment but less than the 13 ìg/g level associated with embryonic teratogenesis (Lemly 1993, Skorupa and Ohlendorf 1991). Sediments collected near the inlet of Pond 1 contained elevated concentrations of chromium, copper, mercury and zinc (Table 8). Concentrations of these elements were at levels considered heavily polluted (Baudo and Muntau 1990).

Table 7. Selenium concentrations (in ìg/g dry weight) in sediment and biota from Soda Lake, Natrona County, Wyoming.

Matrix	Sample Size (n)	Selenium	
		Mean	Minimum - Maximum Values
Sediment	6	1.78	BDL[1] - 3.6
Pondweed	5	2.31	1.25 - 4.4
Waterboatmen	6	7.4	5 - 11.1
Gadwall Liver	2	--	9 - 23.8
Blue-winged Teal Liver	3	29.36	24 - 37.4
Eared Grebe Eggs	3	11.22	9.85 - 12.57

[1] BDL = Below Detection Limit

Table 8. Chromium, copper, mercury and zinc concentrations (in ìg/g dry weight) in sediment samples from Soda Lake, Natrona County, Wyoming.

Element	Pond 1 (n =4)		Pond 2 (n=2)
	Mean	Minimum - Maximum Values	Minimum - Maximum Values
Chromium	624.8	15.39 -1,830	12 - 15.69
Copper	23.5	BDL[1] - 55	7.73 - 13
Mercury	0.52	BDL - 1.4	BDL - 0.06
Zinc	329	16.42 - 887	39.9 - 41.8

[1] BDL = Below Detection Limit

SUMMARY

Petroleum Hydrocarbons

Based on higher PAH levels in sediment and vegetation, one would expect Pond 1 to pose a greater risk to wildlife than Pond 2. However, in invertebrate samples (damselfly and waterboatmen) most carcinogenic PAH's were below detection in both ponds. One possible explanation for the lack of PAH's in the invertebrate samples is that sediment-absorbed PAH's tend to have a limited bioavailability to benthic invertebrates. Aquatic organisms seem to assimilate PAH's more efficiently from water than sediments, thus limited uptake of PAH's from the sediment probably occurs in the interstitial water (Neff 1979; Neff 1985). Pond 1 sediment contained lower levels of aromatic hydrocarbons in 1992 compared to 1986 when the pond was receiving refinery wastewater.

Total PAH's were below detection in eared grebe eggs and juvenile blue-winged teal liver from Pond 2 and gadwall biles from the reference site at Hutton Refuge. At Pond 1, the high levels of metabolized PAH's in juvenile gadwall biles (approximately 600 µg PAH/g) were noteworthy and should be investigated further. The effects of PAH's on waterfowl populations in the field is largely unknown (Peter Albers, U.S. Fish and Wildlife Service, Laurel, Maryland, pers. communication, September 27, 1993). Toxicity can vary with the amount of weathering of the oil and the types and concentrations of PAH's present. Although death from ingestion of oil is not likely, sublethal effects can occur and include: gastrointestinal irritation, pneumonia, damage to red blood cells, immune system suppression, hormonal imbalance, impaired reproduction and reduced growth (Albers 1995). Based on PAH concentrations in dietary items such as aquatic invertebrates and pondweed, the risk of acute effects to aquatic birds is low. Highly oiled sediments at the inlet of Pond 1, if disturbed, may pose a risk to aquatic birds. A visible sheen was observed on the water's surface following collection of sediments from the inlet. Aquatic birds contacting the sheen could transfer the oil from their feathers to their eggs (King and Le Fever 1979). Oil applied to the egg surface in amounts as small as 1 to 5 µl can cause embryo mortality (Leepen 1976, Szaro 1979).

Concentrations of four carcinogenic PAH's in sediment and vegetation ranged from below detection to 3.0 µg/g. Pond 1 samples tended to contain higher levels of each carcinogenic PAH compared to Pond 2 samples.

Trace Elements

Selenium was elevated in aquatic invertebrates, bird livers and bird eggs but not in sediment. Selenium concentrations were above threshold levels shown to cause impaired reproduction and embryonic deformities in aquatic birds (Lemly 1993). Sediments collected near the inlet of Pond 1 contained elevated concentrations of chromium, copper, mercury and zinc.

MANAGEMENT RECOMMENDATIONS

Periodic monitoring of selenium in dietary items such as pondweed and aquatic invertebrates should be done to determine if concentrations are increasing over time. Waterfowl, American avocet and eared grebe nests should also be monitored for selenium concentrations in eggs and for impaired reproduction. The extent of PAH contamination in sediments at Pond 1 should be investigated along with the chronic effects of PAH contamination on resident nesting birds that feed in Pond 1. Chronic effects on aquatic birds could be determined by histopathological studies and biomarkers such as DNA adducts, hepatic mixed function oxidase (MFO) activity and ethoxyresorufin-O-deethylase (EROD) response (Jimenez et al. 1990).

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